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ABSTRACT

This paper, intended to show some misgivings about the potential of the Piagetian research orientation for improving science education practice, was presented at the 1978 meeting of the National Association for Research in Science Teaching (NARST). The research orientation discussed is that derived from the developmental theory of Jean Piaget. The misgivings are grouped under two headings: educational claims and metatheoretical considerations. Discussion of these two areas leads to a consideration of how the Piagetian research orientation in science education could be related to professional practice, with particular reference to curriculum and instructional planning, and to the diagnosis of children's learning. It is suggested that in light of these misgivings, it might be useful to consider an alternative for planning and diagnosing. (Author/HM)

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PIAGETIAN RESEARCH IN SCIENCE EDUCATION:
SOME MISGIVINGS ABOUT ITS POTENTIAL
TO IMPROVE PRACTICE

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Introduction

In this paper, I wish to share some concerns I have about a specific orientation in science education research, namely that apparently derived from the developmental theory of Jean Piaget, an orientation which has generated a considerable amount of research activity within the National Association for Research in Science Teaching. The quality and quantity of this research is not in question here; instead, I wish to show that one could have misgivings about this orientation's potential to improve science education practice.

I discuss my concerns in four sections. In the first, I suggest that it may not be appropriate to speak of developmental stages, and that this way of speaking may be inconsistent with our understanding of development. Next, I briefly show that this research orientation may be somewhat at odds with Piaget's own holistic and structuralist view. In the third section, some stated implications of this research orientation are examined to show that they could be in conflict. The final section reviews the expectations we appear to have of Piaget's theory, and then offers an alternative for dealing with some of the problems that science teachers might face when planning their teaching.

Attaining Concepts and Stages

As a research community, it seems that we are running the risk of becoming careless when we talk about being at one or another stage of development, and about having or acquiring one or another concept, be that a conservation concept or any other concept that might be of interest to science educators. In this portion of the argument, I wish to point out that this way of talking and thus that this way of thinking about development from the standpoint of the teacher, curriculum designer or evaluator can become misleading.

The simplest way to draw attention to the concern that I have is to use the language to be found in some typical studies in science education relating to Piaget's theory. There is some danger in taking this approach, of course, so I wish to underscore that the examples are used not to point out errors but to show how ambiguities can arise and how these in turn can lead us into difficulties. Consider, for example, statements by Novak which are cited by Lawson (1977) in a recent study, and how Lawson himself responds. Novak is cited as saying that there is evidence that children can acquire abstract concepts well before they reach the stage of Piaget's formal operations. Lawson finds that the studies on which these claims are made are defective, for the test items used to acquire the evidence do not themselves demand formal operational thought for their solution. He then contends: "...students who have not yet developed formal operational schemata will not meaningfully comprehend concepts and principles of science such as: particulate theory of matter, DNA, gene, evolution through natural selection, ideal gas, ecosystem, and so on." (pp. 4-5) It seems plain enough that Novak's point hinges on what we mean by acquiring abstract concepts, just as much as (if not more so than) it hinges on evidence. Likewise, Lawson's rejoinder depends on it being clear and acceptable to us, that a meaningful comprehension is conceptually dependent upon the presence or attainment of formal operational thought. A closer examination of the statements just cited makes their difficulty in informing the science education community clearer.

Lawson is arguing that meaningful comprehension depends upon the development of formal operational schema; but so long as a concept is not just parroted (learned by rote--the word and nothing else) and is set within some comprehended sign system (whether that is gesturing or speaking) then it will be meaningful, to some extent, to a child who comprehends the sign system--and that almost by definition. Now, it is true that the concept will not be understood in the same rich and sophisticated way that it is understood by a scientist, yet it will be meaningful.

We could of course take this further by suggesting that only a very few could have a fully developed meaningful grasp of such concepts as DNA, gene, evolution, and so forth. Specifically, those research scientists who are in the thick of examining, testing and extending these concepts and are employing them actively in their investigations are naturally in possession of a deeper and more comprehensive understanding of the concepts than are people like myself who merely talk about them, having learned of them secondhand some years ago without the privilege of having them as the object of sustained study.

While this analysis has pointed to the serious difficulty of being sure what we mean by speaking of acquiring certain specified concepts, it can also be directed profitably at what we might mean when we say that a child is at any particular one of Piaget's so-called stages of intellectual development. In a complex and detailed argument which I shall only touch upon, Toulmin (1971) argues that the concept of stages in physiological and psychological theories ought to be treated only as a descriptive convenience and one which, he demonstrates, is fast losing its usefulness in physiology. Toulmin warns against the temptation to see in physiological development, "...an inherent order and necessity that clearly does not exist in physiological maturation." (p. 52) Just as there is a slow, non-abrupt physiological maturing from the infant to the adult (our concepts again), so there is no distinct single sequence of stages in psychological development. Toulmin goes on:

> The child does not learn, first, to perform all the unit actions he will ever need, next to build these into a complete repertory of standard behavioral sequences, then to treat certain actions as symbolic, etc. Rather he acquires and refines his motor, behavioral, symbolic, and other skills throughout his whole lifetime. So we must begin by considering separately the development of each distinct type of capacity. All the different elements in adult cognition are not just added to one another, in succession, during infancy and adolescence; rather, they fit together in different patterns, at different points in the child's life. (p. 53)

Conceptually, it makes uncertain sense to construct science curricula and teaching strategies according to definitive stages and to what we might suppose that children can logically manipulate within those stages. And, to support this view, there is empirical evidence which demonstrates plainly that these stages of development fail to show their discreteness. Brown and Desforges (1971) report:

> Considerable numbers of studies have been accumulating, casting doubts upon the integrity of stages. Some refer to the surprisingly low correlations between behaviors at a given time, and yet others to the presence of operations commonly taken as representative of much later stages. (p. 9)

They continue, "The exact proportion of heterogeneity which theorists will tolerate without abandoning the stage concept, is an interesting point." (p. 11)

Such findings as these should give us misgivings about the appropriateness of fashioning Piagetian theory to suit our educational needs, and especially about our tendency to be procrustean with this research orientation and what its findings are taken to mean. For instance, in a recent study, Lawson and his colleagues (1974) show that significant gains are made by children as a consequence of their involvement in test-retest situations with Piagetian tasks. This is a splendid study, yet toward the end of this report, the following statements appear:

> Approximately 20% of the subjects are shown as having shifted from concrete to formal thinking patterns on the basis of this analysis. Since only one week of time (sic) elapsed from pretesting to posttesting and no treatment was provided, these apparent gains in intellectual ability are artificial. Clearly, using the battery of tasks as employed in this study and making assertions concerning intellectual gains on the basis of total scores is not justified. (p. 274)

The issue here is how one could call these gains artificial in the absence of a definitive concept of what a real, albeit incremental gain might be, and I doubt that time elapsed will be the distinctive attribute of this concept. As we have seen, such a precise account of an incremental gain is not possible within Piagetian theory. It is not that Lawson, Nordlund and DeVito are wrong in making this claim, it is simply that such a way of speaking is unclear and possibly misleading.

To summarize the concerns expressed in this section, although we tend to speak of children as acquiring concepts and as being in definite stages, there is reason to suppose that this way of talking is misleading. While it may appear to serve our educational ends, it is not clear that it does, neither does it fully correspond with Piaget's theory. Possibly, too, Piaget's theory is misrepresented if it is thought to be able to depict sequential and discrete stage development or maturation. Reasons such as these furnish misgivings about the usefulness of the Piagetian research orientation to our concerns as science educatiors.

Holism, Reductionism and Questionable Expectations

Before proceeding too far with misgivings about the use of the Piagetian orientation in science education, something needs to be said about the relationship between Piaget's perspective and the one it has received at the hands of the education community. It is helpful to recall that Piaget's work is closely tied to that of Kant, and that it is probably intended that the theory be understood within the framework of structuralism and holism. A word from Piaget himself serves to set this straight. In Structuralism (1970) he warns against a reductionist program which reduces vital phenomena to physico-chemical ones, as mechanistic doctrines are simply out of place from his view. He writes:

> Whereas other animals cannot alter themselves except by changing their species, man can transform himself by transforming the world and can structure himself by constructing structures, and these structures are his own, for they are not eternally predestined either from within or without. (pp. 118-119)

There is a caution, for the reading, in what Piaget has said here. His view is quite at odds with the view that Higginson (1977) finds to prevail in educational circles.

> It has been estimated that in over half a century of work in the field Piaget has written the equivalent of fifty five-hundred-page books on child development. All too often this edifice is reduced to an oversimplified description of 'four stages' and educators scurry away to devise diagnostic tests and means for accelerating children through the stages. Hence one gets the ironic situa'ion of having the holistic, constructive Piageian position being interpreted in reductionistic terms with the major focus in application being on those activities children are <u>unable</u> to do. (p. 15)

Later, Higginson comments, "There does not seem, for instance, to be any widespread awareness of the fundamental paradoxes inherent in the very common activity of designing behavioral objectives for Piagetian stages." (p. 16)

An exception to this would be the paper by Kaufman and Konicek, (1974) delivered at an earlier meeting of this association. Their argument, greatly reduced, is that Piaget's view speaks to the child's own construction of reality, and that any attempt to construct reality for the child can only provide a copy of <u>our</u> construction. For Kaufman and Konicek, this latter approach (the one adopted by SCIS) is not Piagetian, and it would be incorrect to maintain that the program and others similar to it are built upon Piagetian principles. Despite the force and merit of this paper, Piagetian work in education continues, but not without complaint.

Smedslund (1977) recently criticized the view we have to take when using Piagetian theory of presupposing the child's understanding a focussing upon his logicality. He points to the danger in this approach as follows:

> It may be objected that Piaget is not really denying the logicality of children at any given stage, but is merely studying the <u>forms</u> of logic they have attained. However, it is a matter of historical record that children who failed on tasks were often simply described as non-logical, and that the problem

> of criteria of understanding has received relatively scant attention in Piagetian literature. (p. 4)

Several critics of Piaget's theory tend to overlook its intellectual origin, and to treat it as remise from a reductionist perspective. In a sense, then, when Smedslund and Brown and Desforges speak of the failure of decalage as an explanatory concept, they appear to be suggesting that each developmental stage ought to possess an integrity. It is not at all clear that a holistic view can be held to task for failing to fulfill reductionist expectations; and, for similar reasons, we ought not to expect from Piaget a precise account of how one stage contributes to the development of its successor, nor how (and which) elements of the environment contribute to the formation of particular schema.

Put another way, the concerns here are that we call instructional devices and plans "Piagetian" when they may not be, and we make Piaget's theory do things which it is not apparently equipped to do.

Manipulation, Matching Instruction to Stage, and Other Troublesome Implications

An amplification of the next set of misgivings requires that we briefly scan some studies with a view to assessing what each suggests are the implications of Piaget's theory for the design and execution of instruction. To assist this task, it is necessary to introduce a conceptual analysis of concepts, appearing in Dearden's Philosophy of Primary Education. (1968) Here Dearden distinguishes perceptual, practical, and theoretical concepts. Perceptual concepts are, "..., such concepts of physical objects and properties as those of tree, flower, dog, bird and stone, red, square, loud, hot, sticky and heavy." (p. 110) Without enmeshing ourselves at all in the problems of ostensive-definitions, we can recognize perceptual concepts as relating to what is publicly and directly manifest. Practical concepts go further, for their use depends on our understanding of the purposes to which we put objects. Examples of practical concepts would be handle, key, clothing, chair, and so forth. Theoretical concepts, for Dearden, are those occurring in intellectual forms of understanding, and it is theoretical understanding that allows a geologist to speak of large rocks in certain places as erratics, and an astronomer to speak of the sun as a star. Of course, the range of theoretical concepts is vast, and includes concepts like gene, DNA, and others that have been mentioned earlier in a previous quotation from Lawson.

It is important to note that the apparent logical priority of these concepts, from perceptual to practical and then theoretical, is not meant to imply an order for teaching them. To assume this would be to commit the fallacy of perfected steps--that the logically prior concept must be completely and perfectly grasped before the next can be understood. (Dearden, 1968, p. 121) Instead, it is necessary just to see (1) that our understanding of concepts offers a potentially useful way of planning the introduction of new concepts in instruction: that is, one moves toward theoretical concepts through perceptual (and possibly practical) concepts; and (2) that this plan flows from analytical rather than empirical considerations. With this in mind, we can examine some claims about what are alleged to be the implications of the Piagetian orientation research.

Raven (1974) provides three recommendations for designing instruction which is meant to promote acquisition of logical operations, which may be stated as follows:

1. The task organization must correspond to the child's level of reasoning.
2. The instructional strategy must incorporate the active engagement of the student in using his logical operations in the construction of rules and concepts, and
3. The use of concrete referents for logical manipulation must be considered in the instructional strategy. (p. 255)

First, the third recommendation: here we see something compellingly similar to what we understand about the difference between perceptual and theoretical concepts. It is by no means clear, then, that this recommendation comes from Piaget's theory, which is not to say that it is accordingly a poor recommendation. On the contrary, Dearden's analysis would suggest that it is fundamental. A similar recommendation is made by Herron (1976) in a commentary on another study. (Sayre and Bell, 1975) Herron offers that, "... if the (authors') suggestion is that the instances of formal thought should grow out of, and be based on concrete experience, I offer my support. Our present knowledge would suggest that such an approach would be helpful." (p. 356) We should add to this that such knowledge is logical in origin and not psychological, though. We should be careful to note here that Herron's point is accurate, but that it would be a mistake to suggest that his point (or Raven's recommendation) follows from Piaget's view, as distinct from any other reasoned analysis of concepts.

In certain writings, the notion of providing concrete referents and the idea (contained in Raven's second recommendation) of active engagement of students have been conflated, to the point of claiming that the actual physical manipulation of objects is necessary for intellectual (and concept) development and, further, that this claim follows from Piaget's theory. Anthony, (1977) in a detailed argument, demonstrates (1) that there is no evidence that direct physical manipulation is necessary, and (2) that this claim is not in any way a deduction from Piaget's theory, although Piaget has said that such manipulation is necessary. (Piaget, 1974, pp. ix-x) Interestingly, as Anthony proceeds to show, Piaget's view on this matter (as distinct from his <u>theory</u>) is not shared by his colleagues Inhelder, Sinclair and Bovet. They write:

> Cognitive development results essentially from an interaction between the subject and his environment. In terms of successful training procedures, this means that the more active a subject is, the more successful his learning is likely to be. However, being cognitively active does not mean that the child merely manipulates a given type of material; he can be mentally active without physical manipulation, just as he can be mentally passive while actually manipulating objects. Intellectual activity is stimulated if the opportunities for acting on objects or observing other

people's actions or for discussions correspond to the subject's level of development. (Inhelder, Sinclair and Bovet, 1974, p. 25)

Our understanding, then must be that mental activity is necessary, but that actual physical manipulation is not. (We return later to the subject's level of development.)

Raven's first recommendation poses rather different problems. Among implications of the literature reviewed by Anne Howe is the following statement: "Teachers should not wait for students 'to become formal operational.' It may never happen." (Howe, 1974, p. 15) And we find a similar persuasion in one of concluding remarks of the now famous Lawson and Wollman study:

> It should be pointed out that the aim of efforts such as those reported in this study, if used on a wide scale in classrooms, should not be to accelerate intellectual development as maintained by Inhelder and Matalon (1960), but to avoid what might be called "stage retardation". Ample evidence exists as mentioned previously, that the phenomenon of stage retardation is indeed widespread. (Lawson and Wollman, 1976, p. 428)

Taken together, the views appear to have us caught between polar opposites: we should ensure that teaching tasks correspond to the child's level of reasoning--that is, we ought to wait; and, we should not wait. Importantly, as I want to show, both positions have some validity.

Piaget's theory is an account of how we come to understand and know the rich variety of concepts shared by the language community we inhabit. As an account, it is probably the fullest and freshest for dealing holistically with the interaction between elements of mind and elements of the environment. Yet, it is not yet clear that it is the sort of theory to tell us precisely how to engineer the environment so that specific elements of it can be made to interact with particular elements of the mind, for that is (1) beyond or outside of Piaget's framework and (2) beyond our possible knowledge in principle. The view that we should not wait gains its validity from the general understanding that, in some way, according to Piaget's theory, the environment contributes to the organism's intellectual development. So, placing youngsters in an artificial environment devoid of formal operational material and speech makes little sense. The other view, shared by Raven and Inhelder, Sinclair and Bovet, can be taken as making the point that teaching at an overly abstract level is not helpful if students have not the ability to understand the discourse at even a primitive level. Both positions are plausible, then, though it is not clear which or either is an implication of Piaget's theory. And, in the shadow of this doubt, misgivings about this research orientation's ability for unambiguously informing practice grow.

Expectations of Science Education and Piagetian Theory, and an Alternative

So far, I have tried to show that there is some cause to be uncertain of the consequences of a Piagetian research orientation for directing the specific selection of instructional strategies in science education. Of course, it is obviously possible (as has been mentioned) to promote formal operational thinking through science teaching, but this could have more to do with providing an overall environment (and the youngster lives in a rich and diverse one aside from his brief but regular visits to the science classroom) than it does with providing very specific elements of that environment with the expectation that stage development will occur and that that development is a function of those elements and only those elements. Nevertheless, it is the case that major institutional and public expectations are held of science education in this regard.

Hale, for one curriculum project, puts it this way:

> An important part of the mission that the ISCS materials were designed to accomplish was to help the student make the transition from (the) concrete operational stage to what Piaget has called the "formal-operational stage" . . . In short, the materials are designed to help the student to gain the ability to think more abstractly. (Hale, 1976, p. 559)

For me, this is a transparent signal that the Piagetian influence has led the science education community away from what might be considered as its most fundamental problem: introducing youngsters to science in such a way that they understand that discipline so far as it is feasible and desirable for them to do so. Evidence of the extent to which our course of inquiry has veered away from this important matter may be found in the following statement by Lawson and Wollman:

> One must not be misled to interpret Piaget's theory as implying that maturation of the nervous system is sufficient for the development of formal thought. If this were the case, the job of our educational system would be small indeed. (Lawson and Wollman, 1976, p. 413)

On this latter point, I think that the authors are mistaken. They have seemingly overlooked the enormous job that education could well attend to, that of initiating youngsters to our culture. After all, without acquaintance with the richness, variety and origins of a culture's concepts there is little opportunity, save by chance, for youngsters to develop our intellectual understandings as the need arises. In my view it is a grave matter to appraise this task as small.

It would be a graver matter, though, to suppose that the Piagetian research orientation alone provides us with the key to planning teaching which can definitively promote intellectual development through to what we can term loosely adult reasoning. The problem in this view is that it tends to neglect the necessary relationship between our language and any theory we care to develop in psychology (or any other discipline) which employs the language, thus leading us to suppose that the discipline has afforded us with special insights, whereas the insights come from our use of language per se. (Two points could be made before this argument is entered. First, we need to acknowledge that we speak of mental states or events because we view it as important to do so. Second, to suggest that speaking of these things is inappropriate is to travel the behaviorist course and since that journey is antithetical to Piaget's, the objection would be out of order, in the present paper anyway.)

Central to our use of mental language is the need to employ terms which technically imply a state or a process by calling attention to the conclusion of that state or process. To abbreviate a point of Daniels (1975) we use such terms as infer to speak about mental processes only after we have judged that the final spoken step is an inference; and the technical knowledge of what an inference is gives us the means to speculate and thus to label what is thought to have happened in the head. In this manner, we label ex post facto most, if not all, mental states and events. The endeavor has been rich and rewarding, too, for we have at hand any number of ways of speaking about things which are of concern. But the endeavor is also limited, for it is inextricably tied to the language we have, and to the logical relationships imbedded within that language.

As Daniels takes pains to show, this is the bedrock of cognitive psychologies and, in short, none of them can go further than the language allows. (In some cases advances can be achieved by using languages other than English. Yet here too, the work is restricted to the rules which inhere in languages like algebra and so forth.) The implication of this point for science education is that it is not necessary to rely upon a formulation such as Piaget's for the ordering of the concepts we wish to teach. Ultimately, Piaget too relies on language and logic available to him, and so our purposes might be equally served by considering the concept or mental skill we wish to teach from a logical position alone, by analyzing what possessing this concept or using this skill entails, and by structuring the teaching to ensure that the entailments are present. This does not deny the place of empirical determination (to see if we are successful) in our work, it simply places the burden of a base for structuring teaching upon logic instead of psychology. Peters puts the upshot of the matter thus:

> The point is often made nowadays by educators influenced by Piaget that children cannot form certain concepts unless they have first formed others, though it scarcely needs elaborate experiments to establish this. (Peters, 1972, p. 475)

I think that these points can be clarified by examining some specific cases in which children are having difficulty with science concepts. As the analysis of each case demonstrates, it is possible to diagnose each problem in terms other than those of a developmental theory and in such a way that the explanation of the problem might be transformed readily into a prescription for instruction. These cases are from reports of student teachers who were asked to keep anecdotal records of the problems which their students seemed to be experiencing.

Case 1: The Prehensile Eye

> Grade 11 students failed to understand that for the eye to perceive an image, light rays must travel from the object to the eye, and not from the eye to the object. Using ray diagrams, students consistently made the mistake of putting arrows on the rays of light, going from the eye to the object. (The students have had at least three weeks of optics, which included ray diagrams to illustrate reflection at a mirror.)
>
> Because of the misconception, they had difficulty understanding how light refracts when travelling from water to air in a demonstration showing that the object in water appears closer than it actually is.

The conception of light held by Euclid and Hero of Alexandria was that of the so-styled "prehensile eye". An analysis of their work and this view appears in one of the senior high-school units developed by the Patterns of Enquiry Project (Finegold and Olson, 1972), and it is shown here that this view precludes coherent explanation of refraction although it adequetely explains reflection as shown in Hero's theory of mirrors. For students to be assisted in understanding that the concept is inadequate, and thus for them to see the point of the concept of light that the teacher is pressing for here, they could be confronted with some phenomenon which cannot be accounted for by the prehensile-eye view. So there are at least two ways of speaking about the students' trouble: one involves talking about the students' intellectual development, and might follow from a theory such as Piaget's; and another would offer that the unwanted conception is adopted because it has worked thus far, and so the students have not found cause to abandon it. The latter treatment, of course, stems from an account of the concept's development in science per se.

Case 2: Real and Virtual Images

> Grade 11 students did not understand what real and virtual images were, when they studied plane and curved mirrors. The teacher thought that an explanation about a real image exposing a piece of photographic film would be easy to understand, but this was not the case. The offered definitions were:
>
> Real image: Formed when using a curved mirror. Can be projected on to a screen. Light rays will expose a piece of film when held at the focal point.
>
> Virtual image: Formed when using a plane mirror or a curved mirror, when object placed between focal point and vertex. Image cannot be projected on to a screen. Image exists behind the mirror, no rays of light come from the image.

One way of looking at this case is to consider what is needed to assist the youngsters in making the transition from the perceptual concepts surrounding reflection to the theoretical concepts of real and virtual images. Perhaps it is simply that a virtual image is seen and so it is termed "real" in a perceptual and ordinary use of that word. That an image is virtual or real takes us beyond a regular vocabulary, and demands that we employ a different convention--one that might be better understood if it can be shown that it becomes necessary in optics to distinguish between the two types of image.

Case 3: Heat of Mixtures

> The teacher had students mix equal amounts of cold and hot water (of known temperature), and then had them measure the temperature of the mixture.
>
> The teacher comments that although they could handle the mathematics, they seemed not to grasp that the heat lost by the hot water equals the heat gained by the cold.

A reading of Duane Roller's (1966) study of the rise and decline of the Caloric Theory plainly shows that what the students are to grasp here is an assumption, principle, or conceptual tool, which was used by Joseph Black in his work on latent and specific heats, and which he called "the equilibrium of heat". At one level of learning, we could simply have students "learn the law", perhaps by rote. Yet if we seek an understanding, we must first broach the matter of what a principle is invented for, and how this particular principle was important for Black to introduce in his work.

Now the point of drawing attention to classroom difficulties such as these is to emphasize that there are alternative ways to invoking psychological theories of development for speaking about why, possibly, the problems exist and how, possibly, they might be resolved. It is not that a developmental theory can or cannot explain these phenomena; instead it is to suggest that if we have misgivings about a theory and about its implications (stated or assumed) for science education, and if we have another way of looking at classroom learning problems it might be as well to give them some time, for they appear to be useful.

Concluding Remarks

None of what has been advanced in this paper has attempted to find fault with Piaget's theory itself, that is not the point. Rather, the point has been to consider the Piagetian research orientation in science education, and to show that reasonable misgivings can be entertained about the potential of this orientation for assisting the practice of science education. So the paper is speculative and must necessarily leave several questions untouched. The dominant question which it raises, though, is if the orientation can assist the planning of teaching and diagnosing of learning in a way that, for example, an analysis of the concepts we wish to teach cannot. Perhaps of equal urgency is the question of which understanding we wish youngsters to have of a concept out of the many there are for any given concept in science. Until we untangle this issue, it will remain unclear what we mean by wanting youngsters to acquire a certain concept.

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